Latest results from new physics searches in MicroBooNE

HEP2023

Luciano Arellano

on behalf of the MicroBooNE collaboration

Jan 12, 2023

Overview

The MicroBooNE experiment

Sterile neutrino oscillation

Heavy Neutral Leptons and Higgs Portal Scalars

Other MicroBooNE BSM searches

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The MicroBooNE experiment

Sterile neutrino oscillation

Heavy Neutral Leptons and Higgs Portal Scalars

Other MicroBooNE BSM searches

The MicroBooNE experiment

Liquid argon time projection chamber (LArTPC)

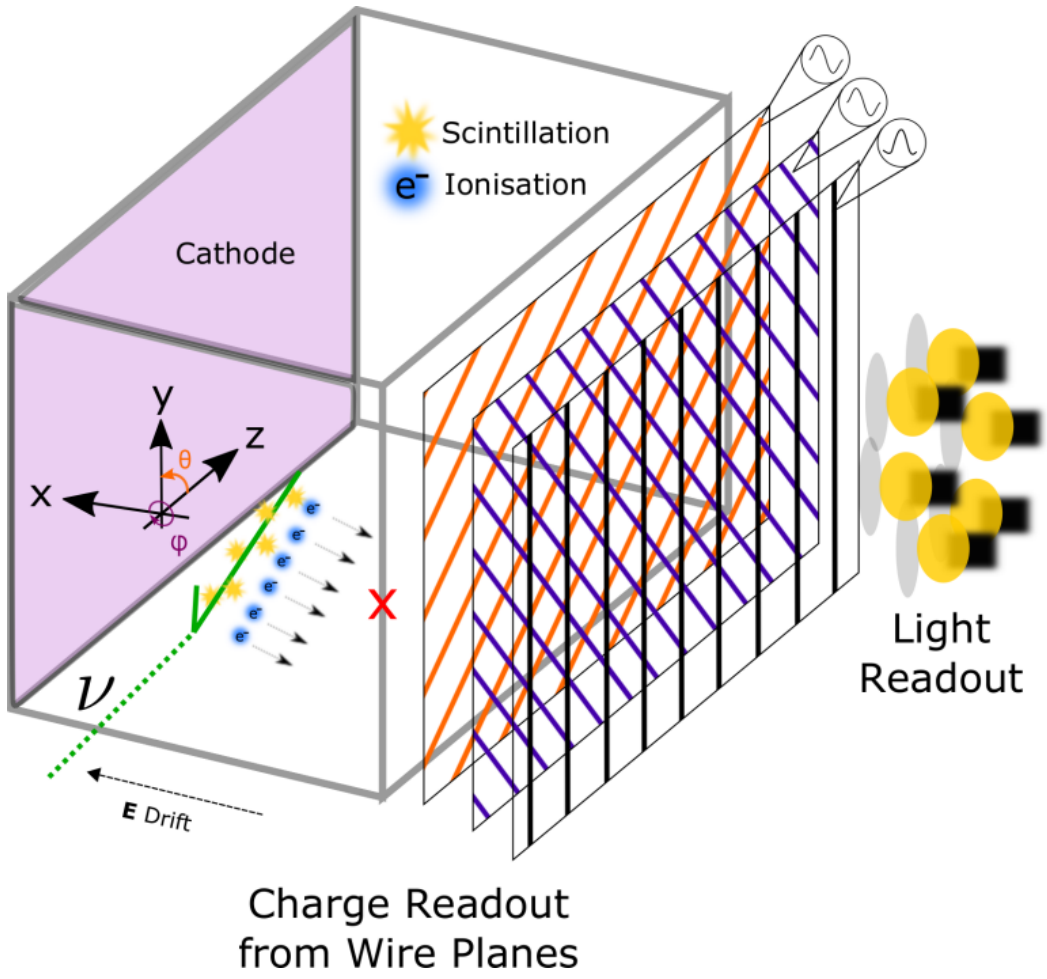
Active volume 85 tonnes of liquid argon $2.6 \times 2.3 \times 10.4$ m^3

Largest dataset of neutrino interactions in liquid argon (2015-2020)

175 collaborators from 37 institutions in 5 countries

May 2022 Collab meeting @ Rutgers

MicroBooNE LArTPC technology



Scintillation and ionization signals used to produce bubble-chamber like images of events

3 planes of wires with 3mm pitch

Array of 32 PMTs for light readout

Excellent mm-scale spatial resolution

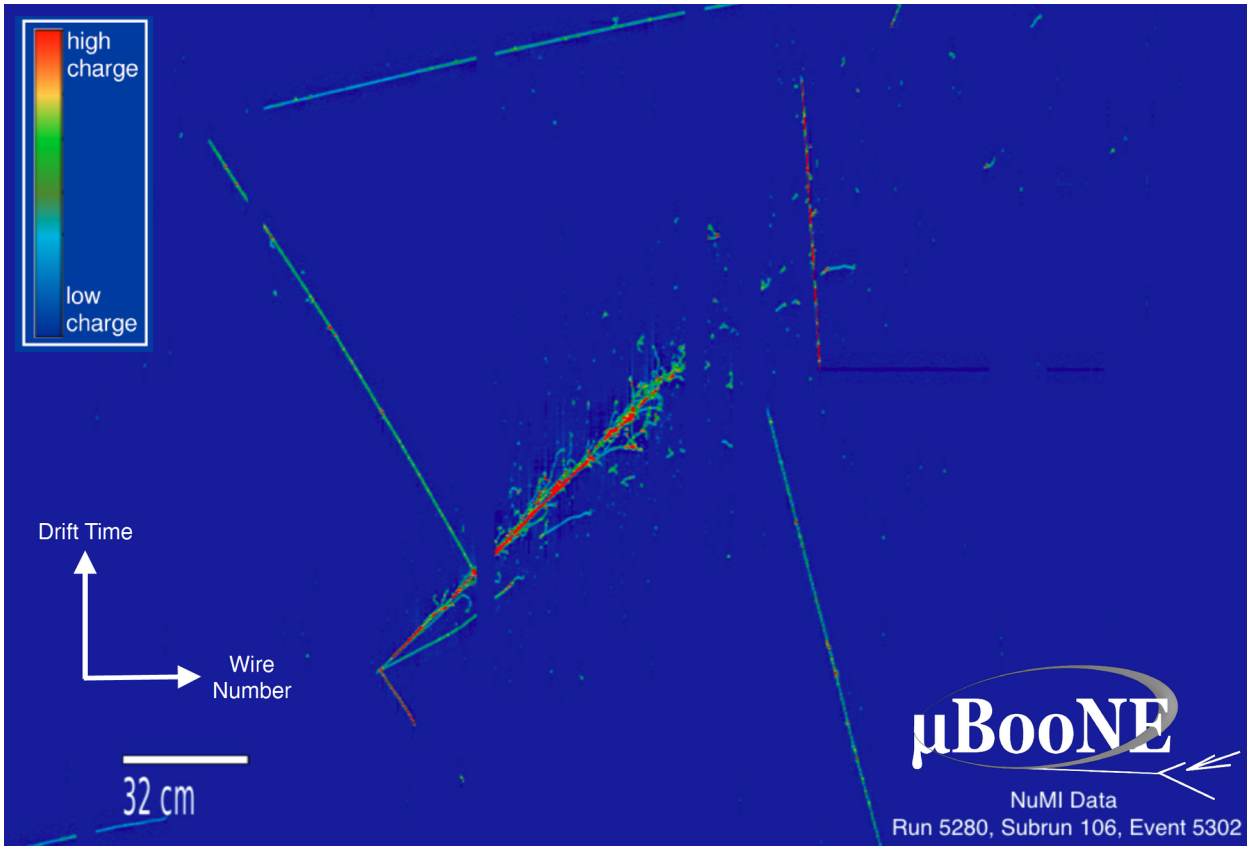
Excellent calorimetry and low-energy reconstruction thresholds

LArTPC – event display

Powerful particle identification

Can reconstruct full 3D image from the wire planes (and scintillation flash)

Color is linked to deposited charge → calorimetry



Phys. Rev. D 103, 052002

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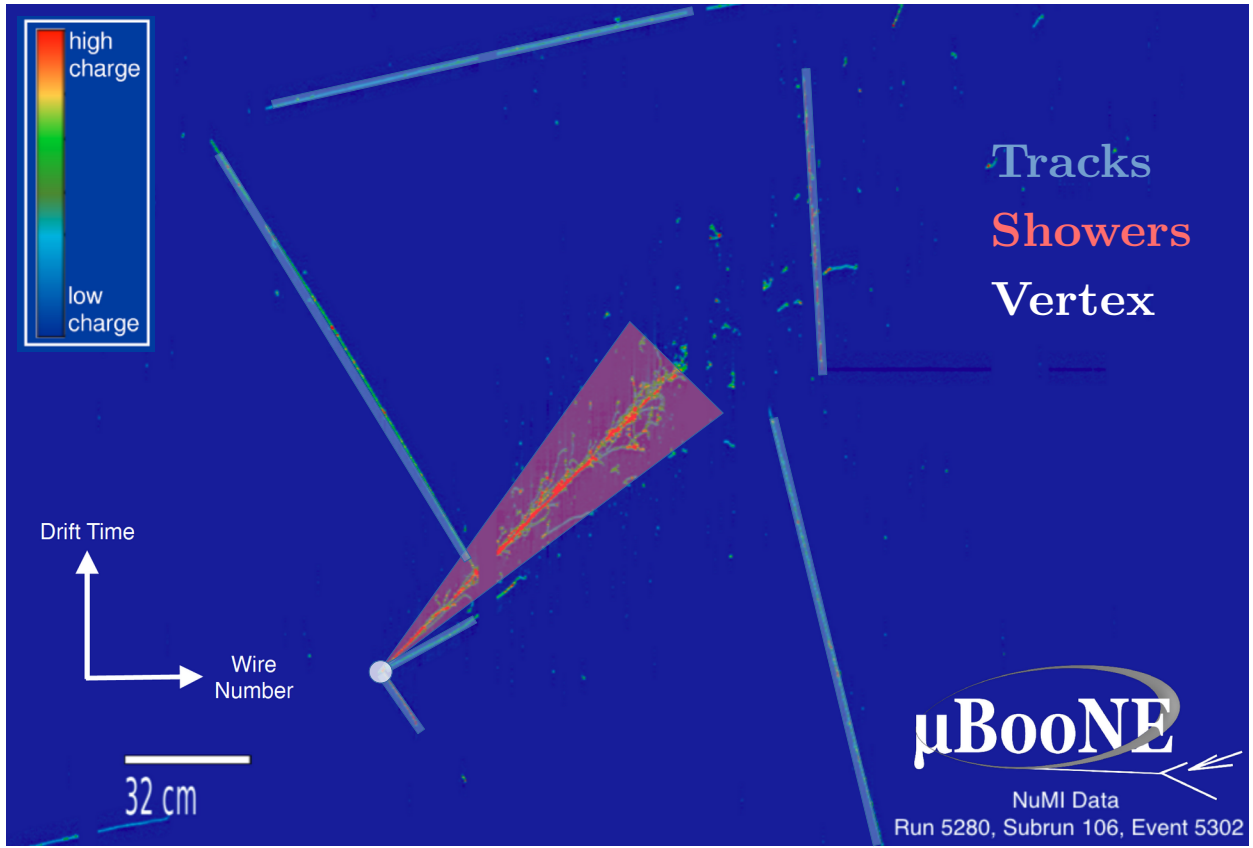

Phys. Rev. D 103, 052002

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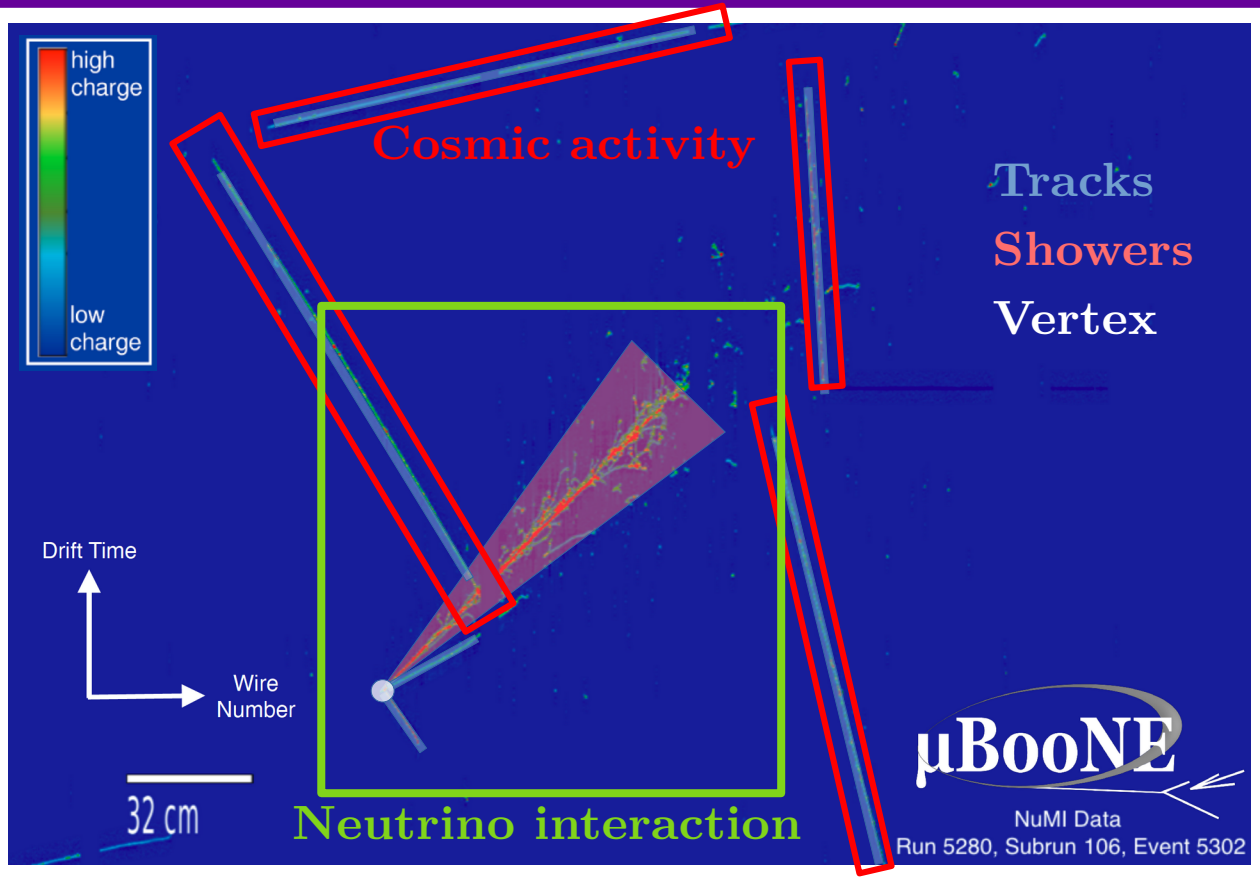
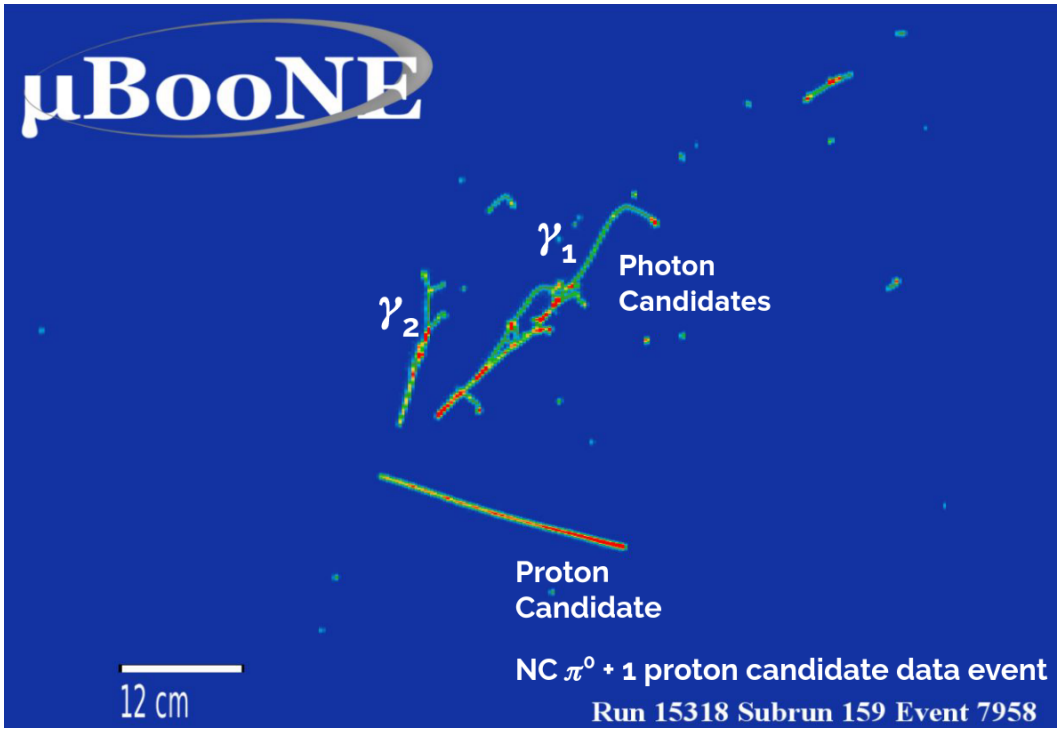
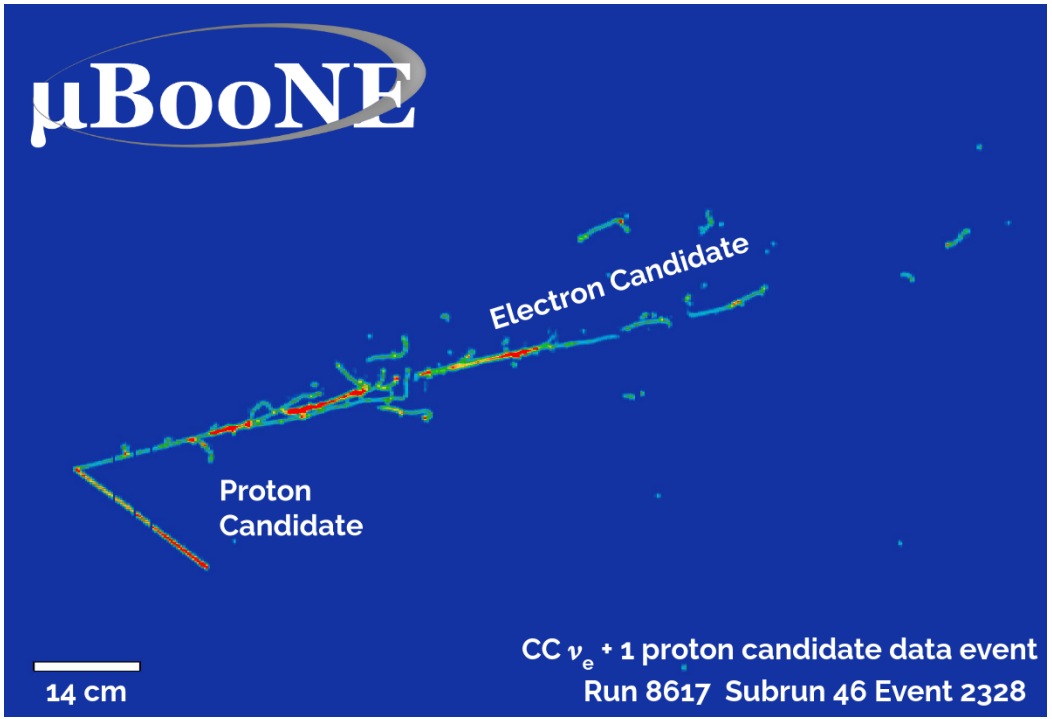


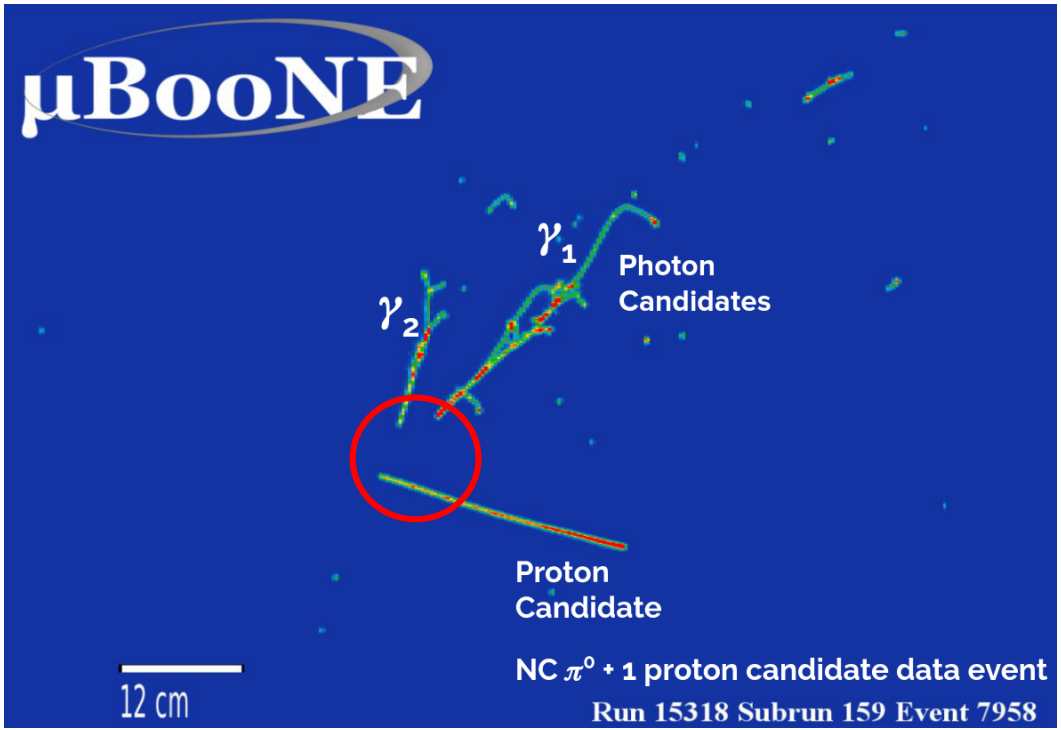
Phys. Rev. D 103, 052002

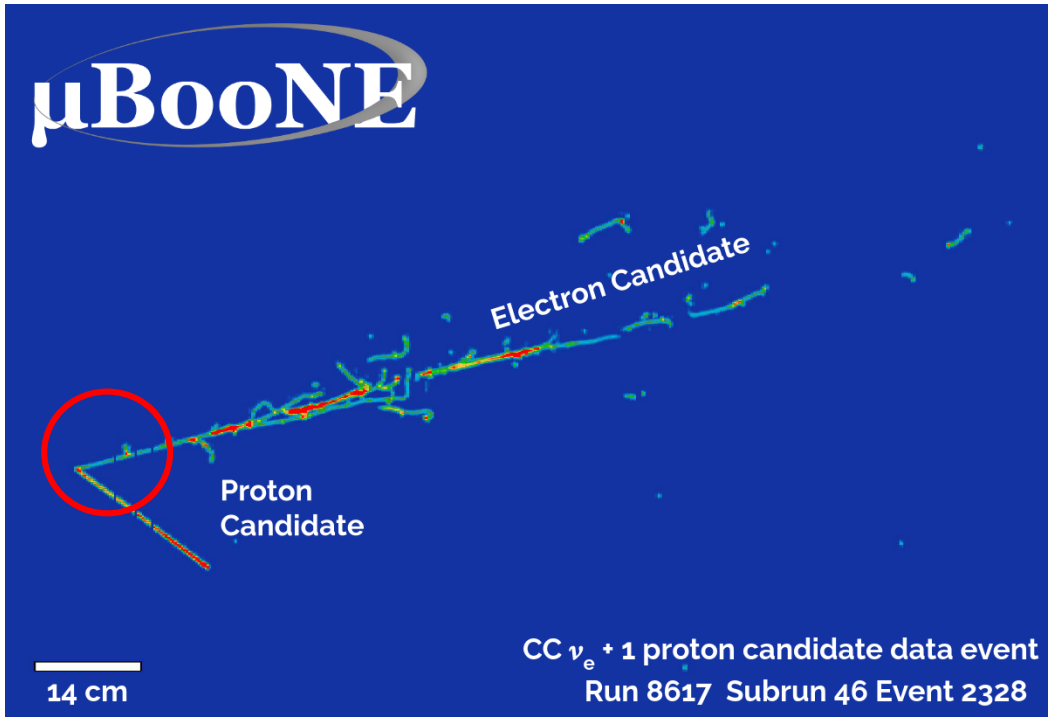
Electron/photon separation in LArTPCs





Electron/photon separation in LArTPCs

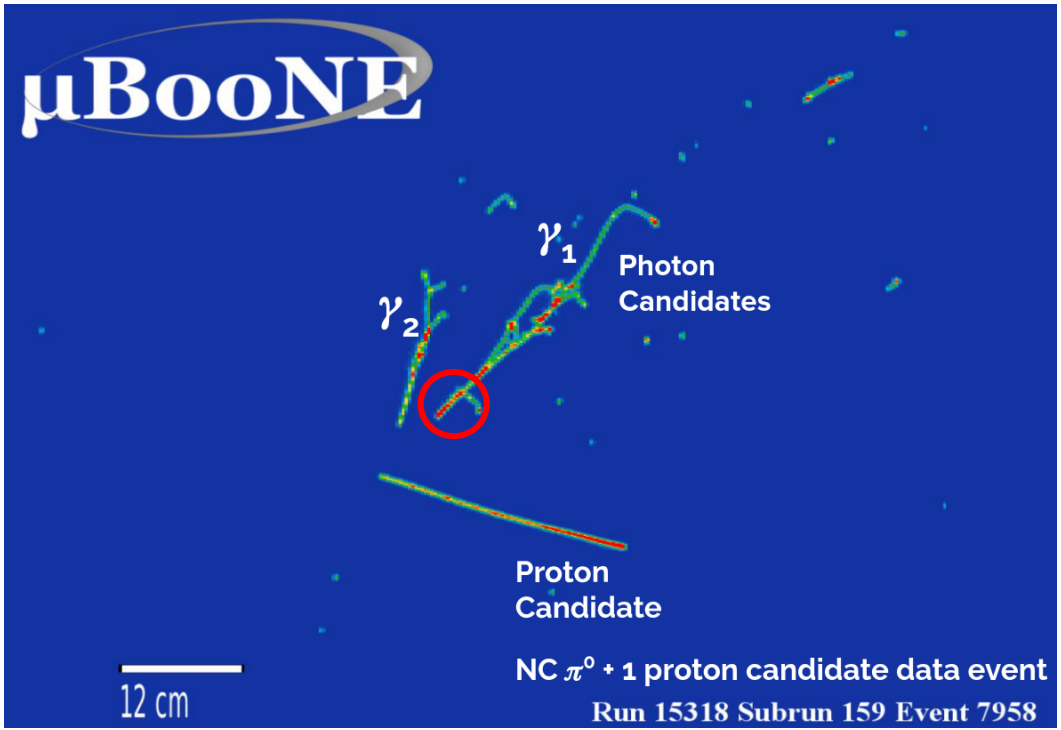


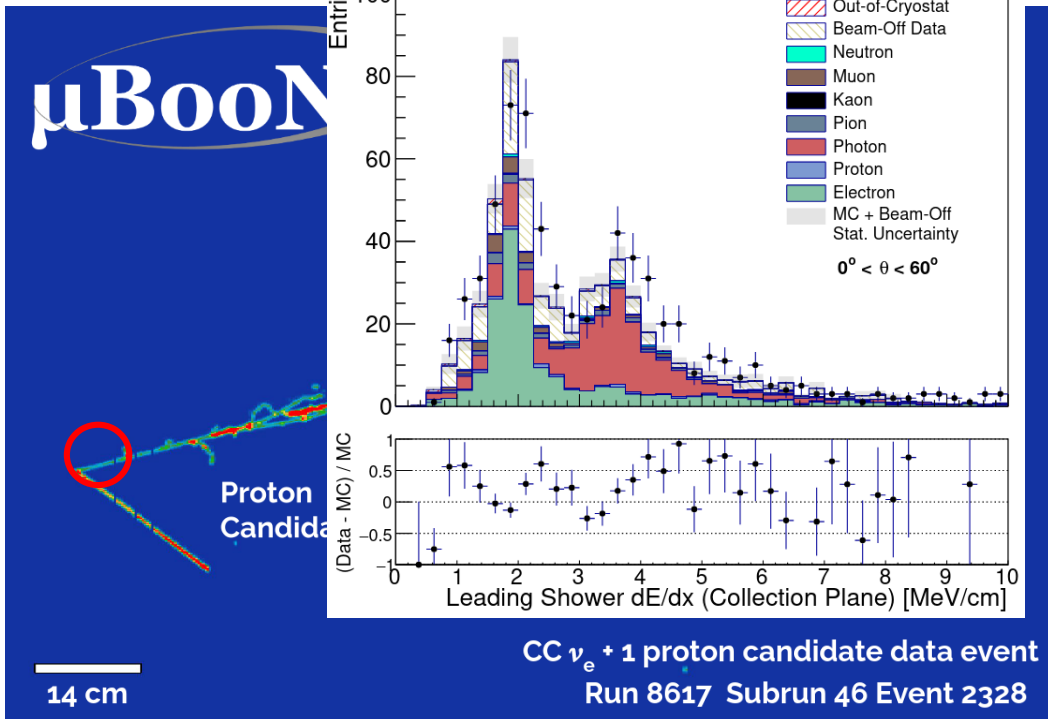


Photon initiated showers have distinct gap between interaction vertex and start of the shower, electrons do not.

Electron/photon separation in LArTPCs

Phys. Rev. D 104, 052002

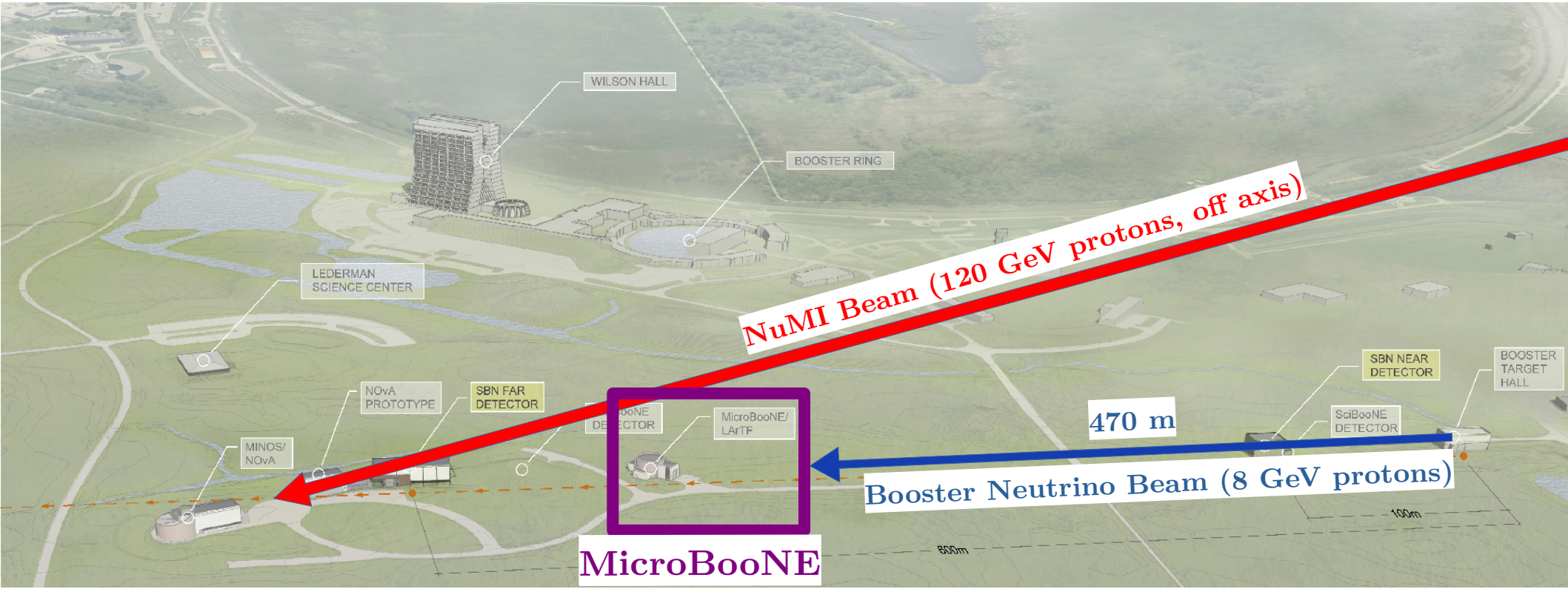




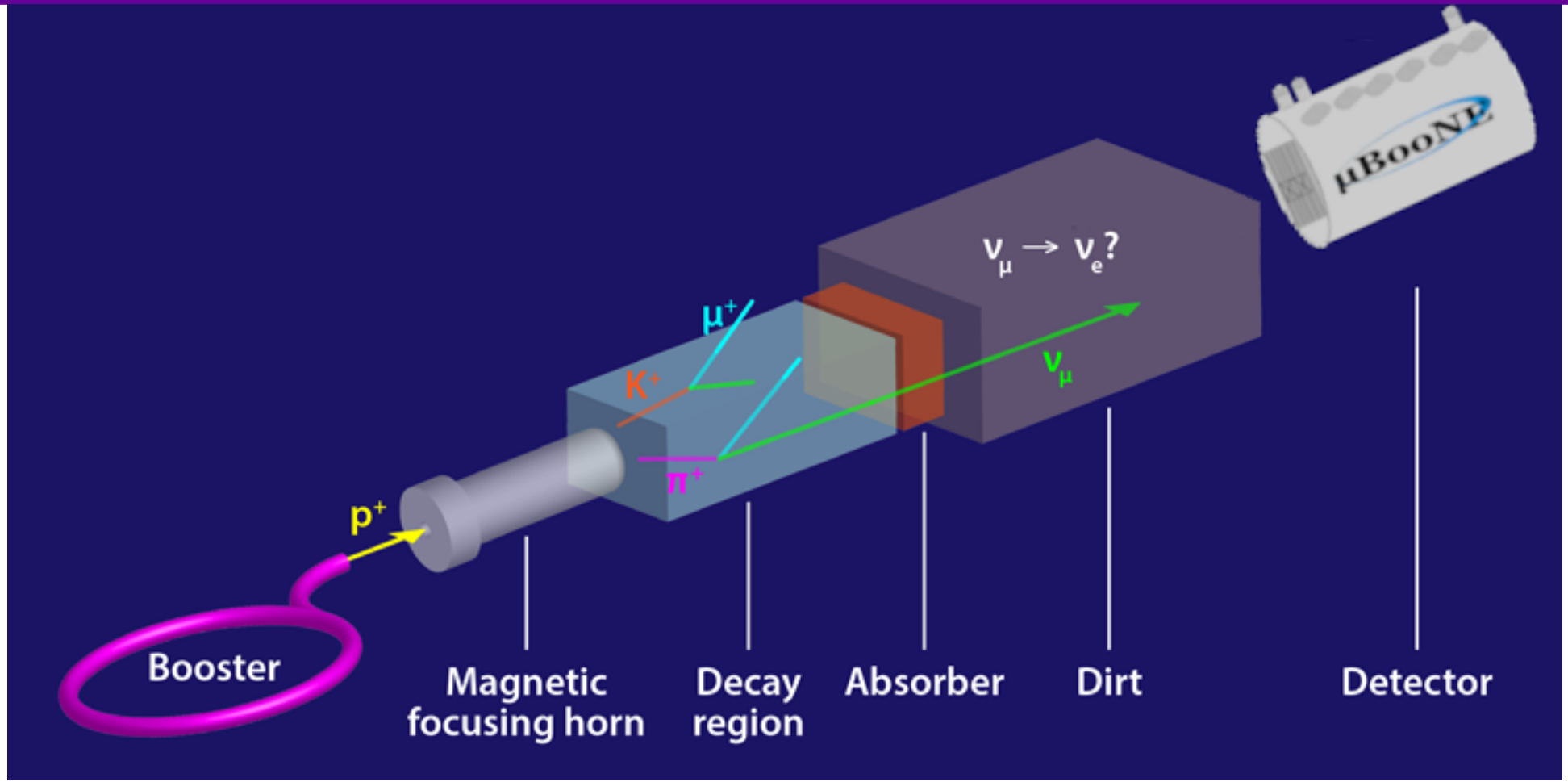
Starting segment of photon initiated shower has double the deposited charge ($\gamma \rightarrow e^+e^-$)

BNB and NuMI neutrino beams

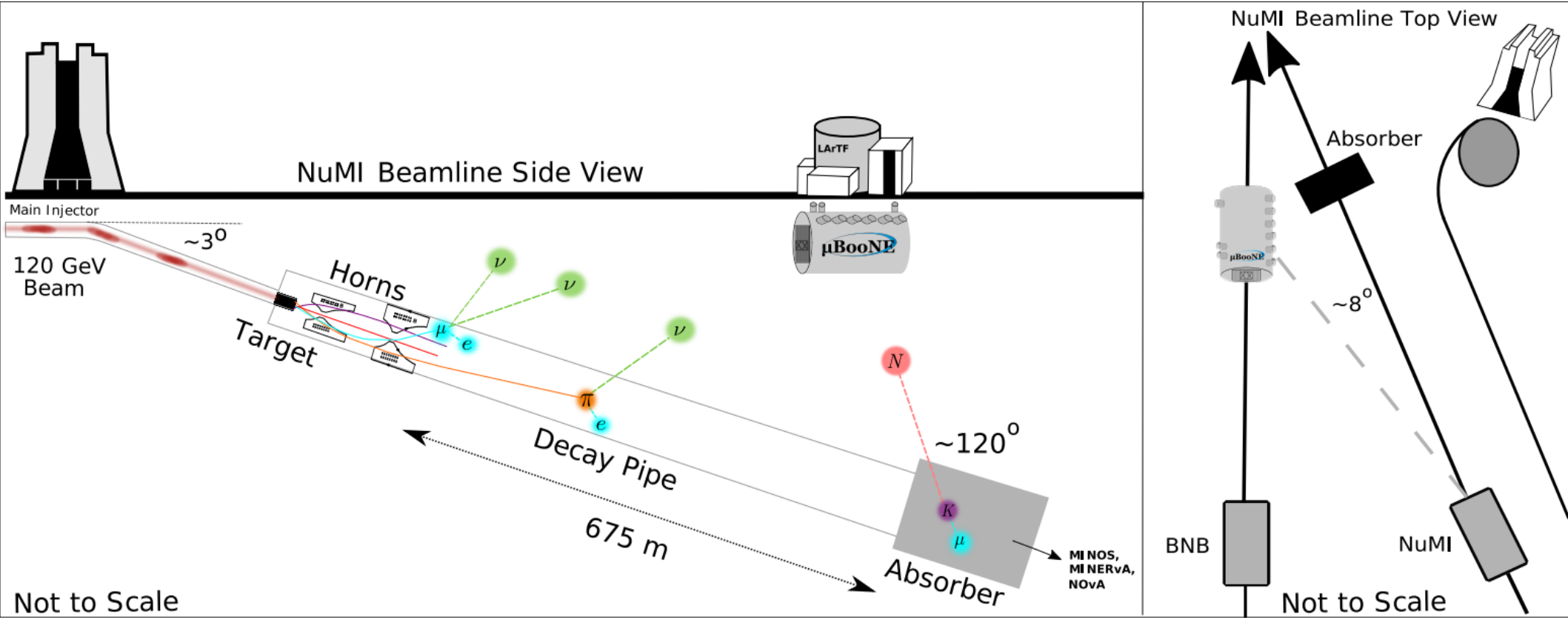
Aerial view of Fermilab, Batavia, Illinois, USA



Neutrino beam (on-axis)



Neutrinos from the Main Injector (NuMI) neutrino beam



13% of beam protons don't interact with the target.

They can produce kaons at the absorber (~100 m from MicroBooNE).

Overview

The MicroBooNE experiment

Sterile neutrino oscillation

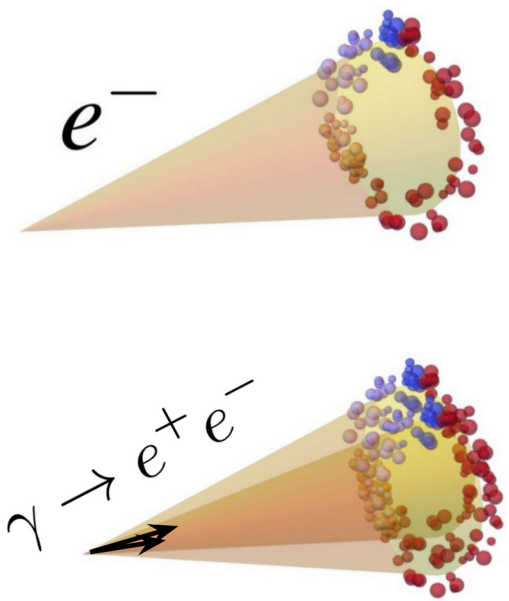
Heavy Neutral Leptons and Higgs Portal Scalars

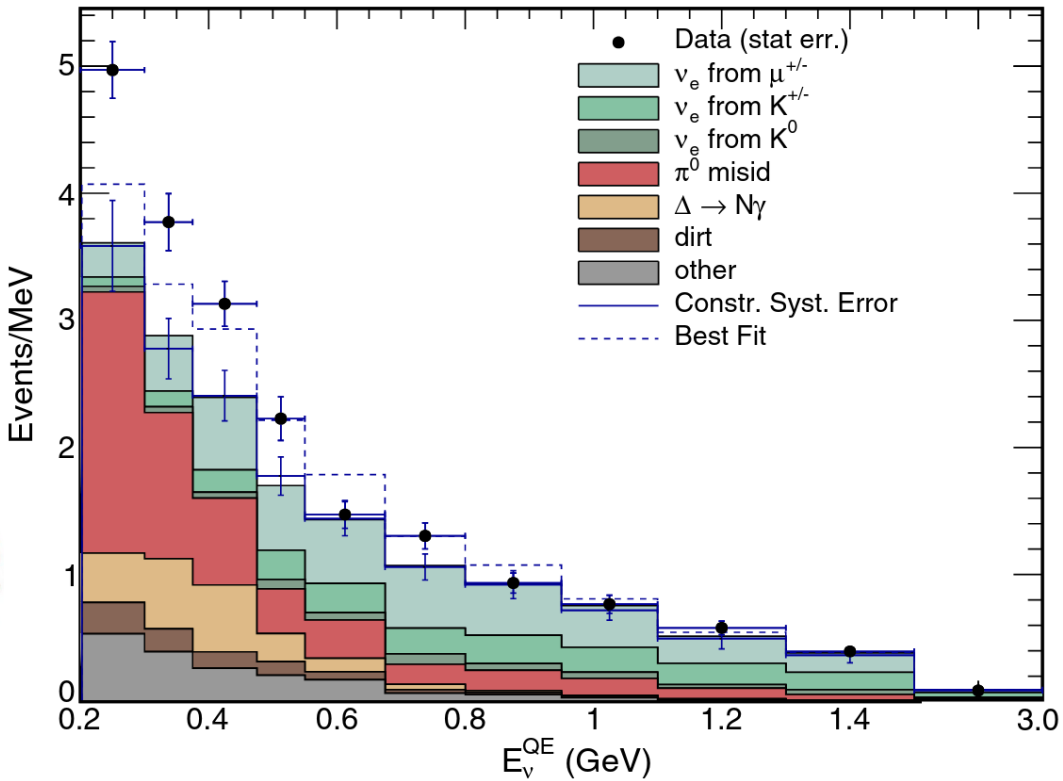
Other MicroBooNE BSM searches

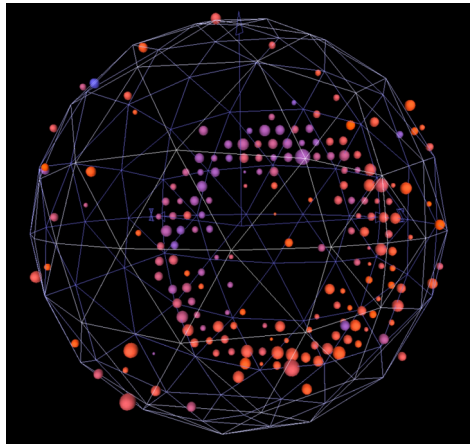
MiniBooNE low-energy excess (LEE)

MiniBooNE (2002-2019) observed a LEE of electromagnetic events with 4.8σ significance.

As a Cherenkov detector MiniBooNE is unable to distinguish between electrons and photons.



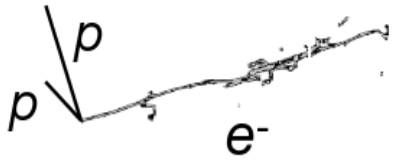




MicroBooNE search for the MiniBooNE low-energy excess

Searches using multiple topologies and reconstruction methods: Phys. Rev. Lett. 128, 241801
We found no evidence of a ν_e excess

Phys. Rev. D 105, 112003



Phys. Rev. D 105, 112004

Phys. Rev. Lett. 128, 111801

Phys. Rev. D 105, 112005

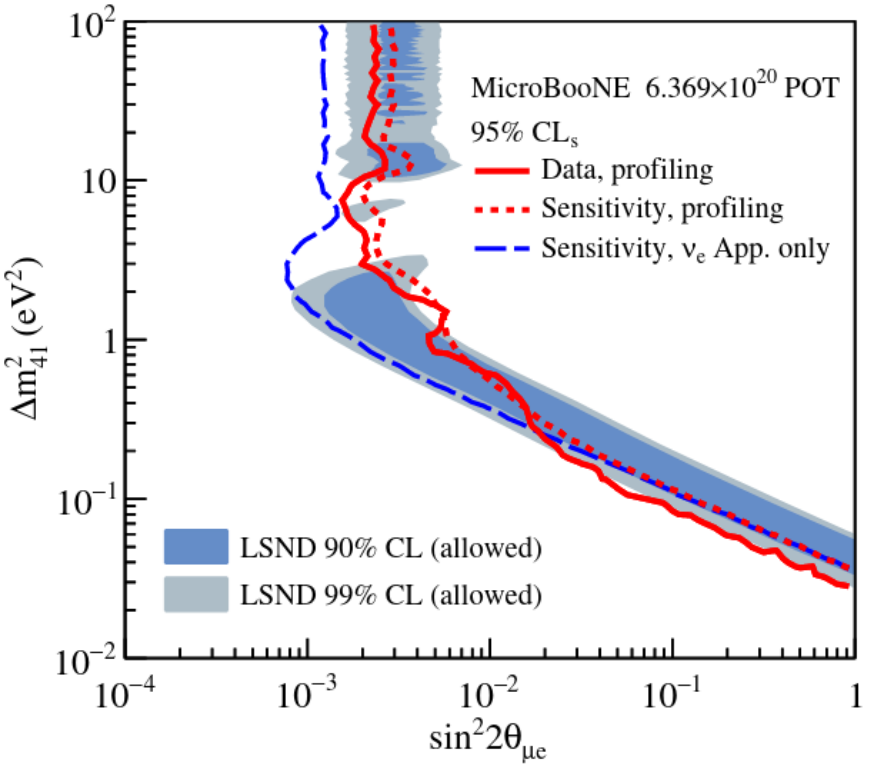
3+1 light sterile search

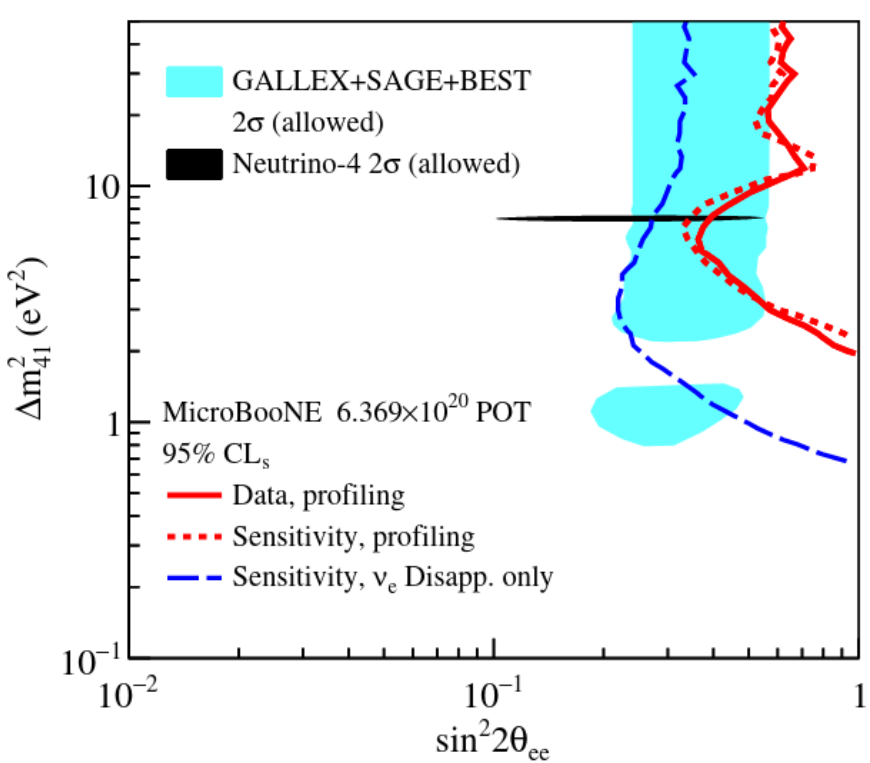
Phys. Rev. Lett. 130, 011801

Full 3+1 search, extended 4x4 PMNS matrix, relevant elements $|U_{e4}|^2$, $|U_{\mu 4}|^2$, $|U_{s4}|^2$, oscillation parameters Δm^2_{41}, $\sin^2\theta_{14}$, $\sin^2\theta_{24}$

Data consistent with 3ν hypothesis, exclusion limits calculated using CL_s

Limiting factor is degeneracy on ν_e disappearance and appearance, will be addressed using NuMI beam





Overview

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Sterile neutrino oscillation

Heavy Neutral Leptons and Higgs Portal Scalars

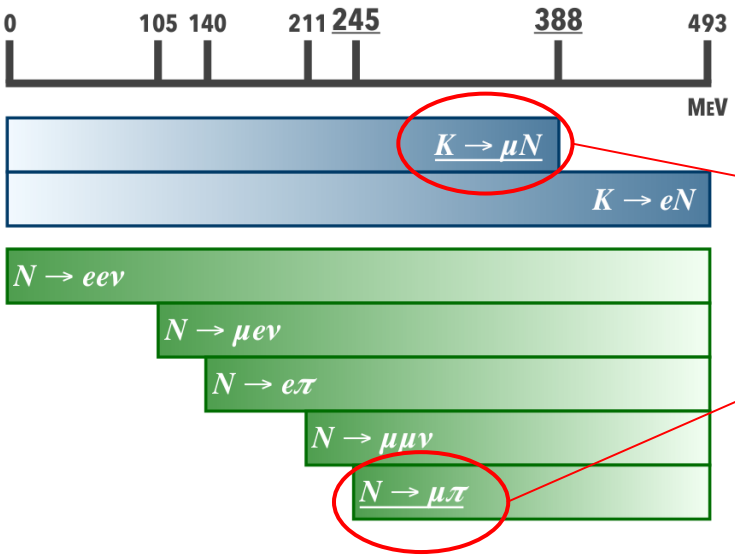
Other MicroBooNE BSM searches

Heavy Neutral Leptons (HNL)

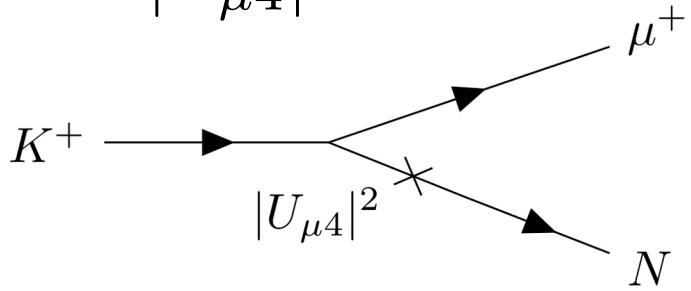
Extension of the PMNS matrix $|U_{\alpha 4}|^2 \, (\alpha = e, \mu, \tau)$

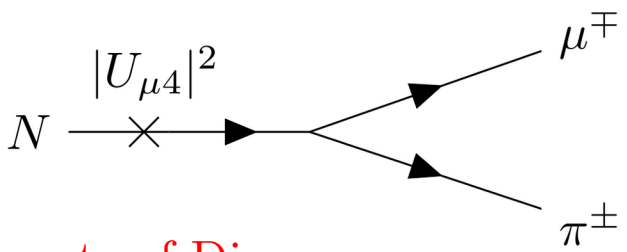
Flavor eigenstates $\nu_\alpha = \sum_i U_{\alpha_i} \nu_i + U_{\alpha 4} N$

We set $|U_{e4}|^2 = |U_{\tau 4}|^2 = 0$ and place limits on $|U_{\mu 4}|^2$



Focused on these production and decay channels





Majorana HNL double the rate of Dirac

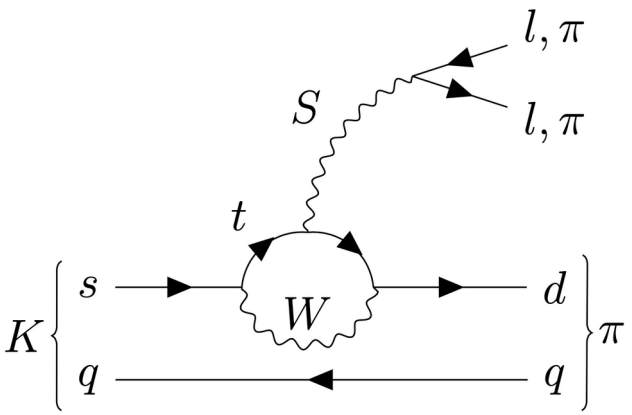
Higgs Portal Scalars (HPS)

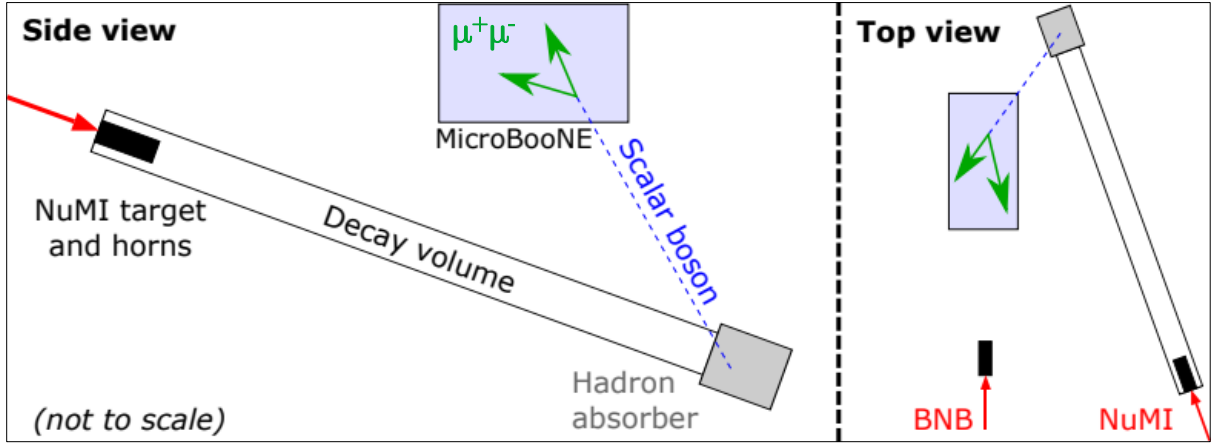
Portal between SM and dark sector via the Higgs

Neutral real singlet scalar boson mixes with Higgs boson with mixing angle θ

Dark scalar acquires coupling to SM fermions proportional to sin(θ) → θ

Further reading: [Phys. Rev. D 100, 115039]





Production via Kaon decay at rest in the NuMI absorber

$m_k - m_\pi \simeq 354$ MeV → decays to e^+e^-, $\mu^+\mu^-$, $\pi^0\pi^0$, $\pi^+\pi^-$

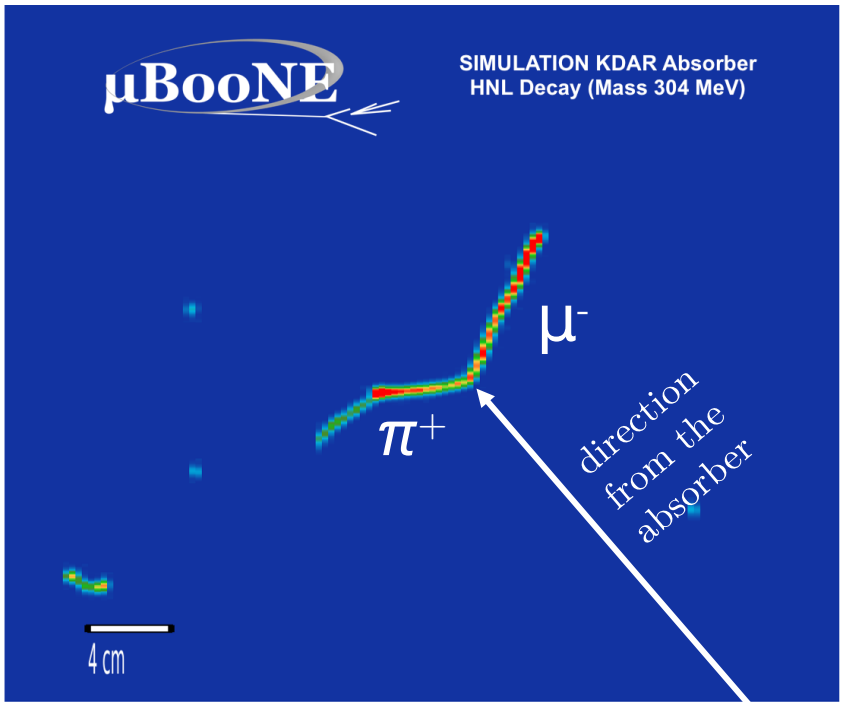
2022

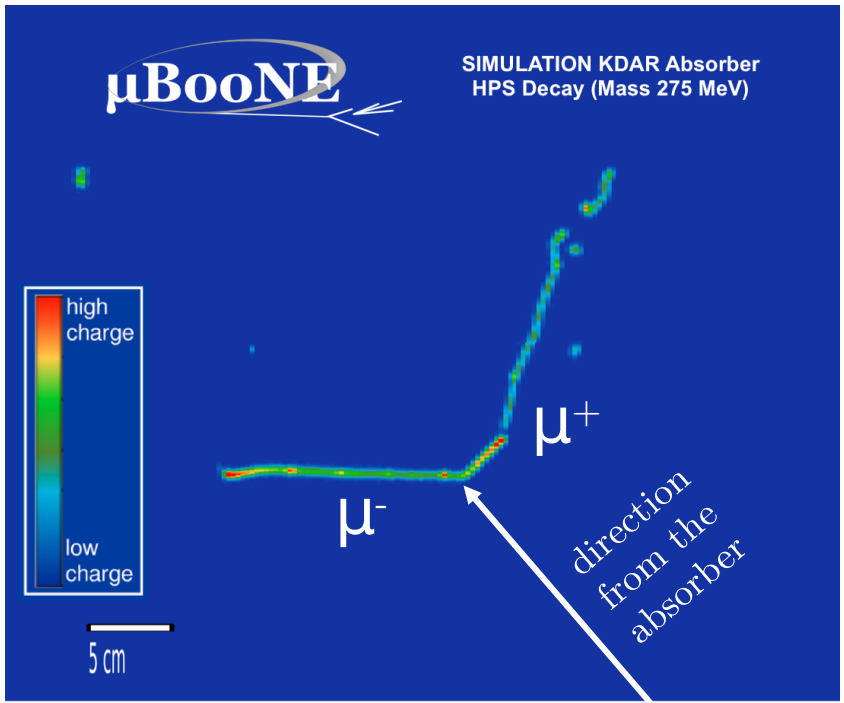
Latest HNL + HPS search (2022)

Searches for HNL and HPS from KDAR from **NuMI absorber**

HNL: BNB target (2020) → NuMI absorber (2022)

Similar two-track topology → similar selection strategy



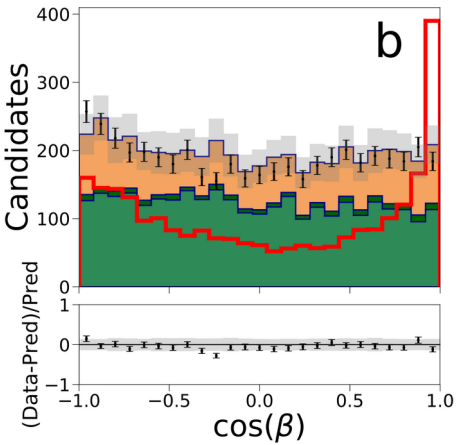


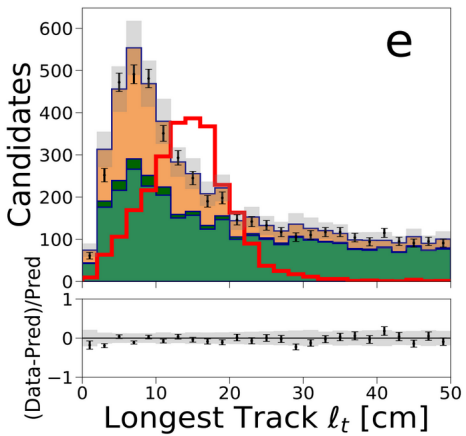
Phys. Rev. D 106, 092006

Search strategy

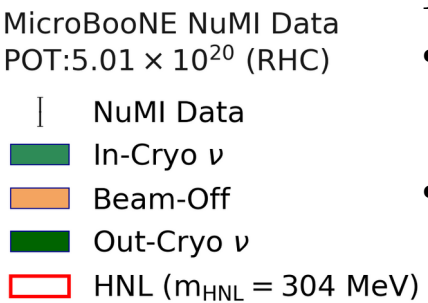
- Simulate signal
  - HNL: 12 mass points $246 \leq m_{\mathrm{HNL}} \leq 385$ MeV
  - HPS: 8 mass points $212 \leq m_{\mathrm{HPS}} \leq 279$ MeV
- After preselection, train separate BDTs for each sample using *xgboost*

A couple of selected background kinematics (for full set see next slide):





β = Angle w.r.t. absorber

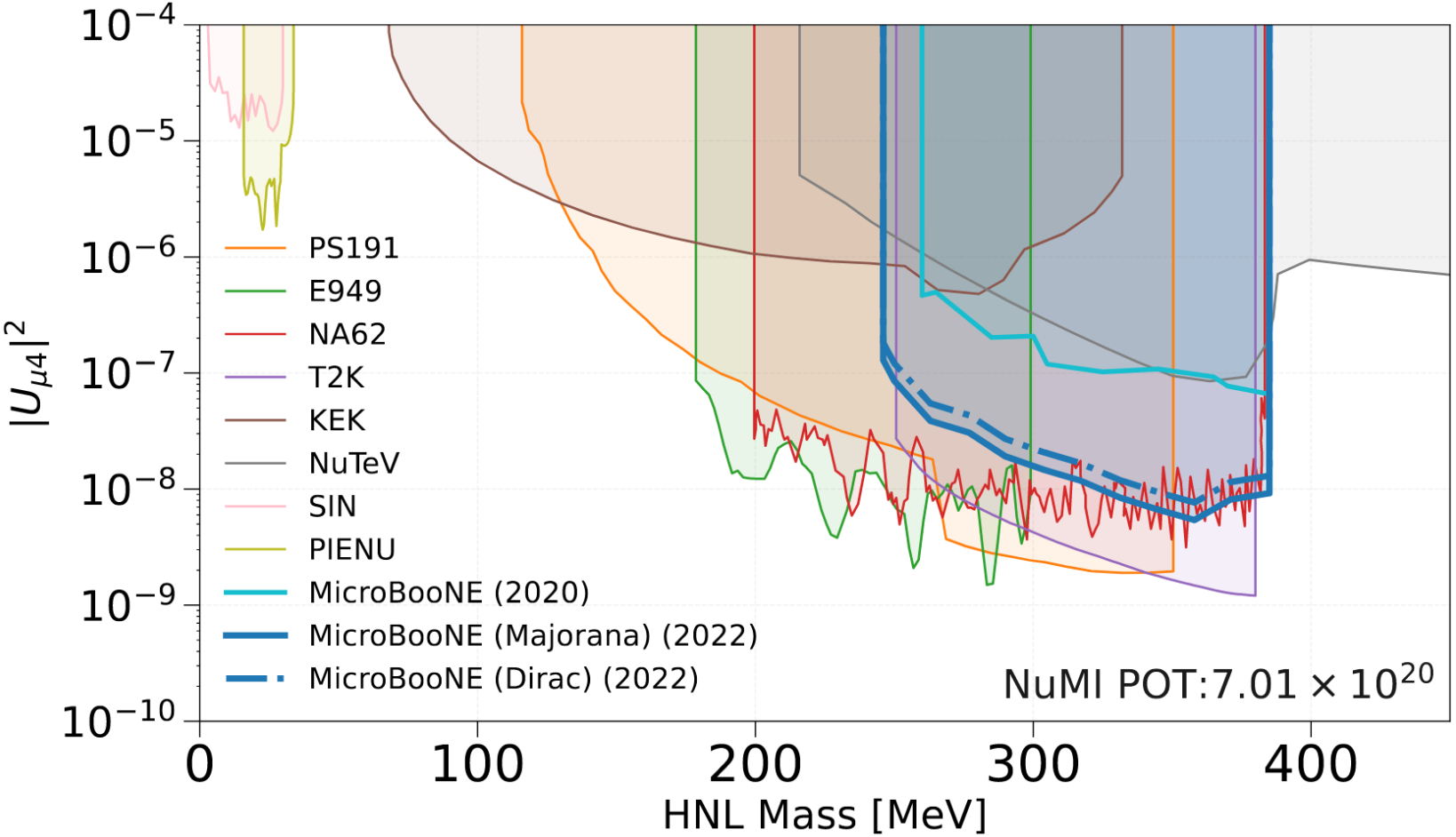


Backgrounds:

- Beam-off: detector triggered by cosmic ray
- In/Out-Cryo: neutrino interactions in/out of the detector

Phys. Rev. D 106, 092006

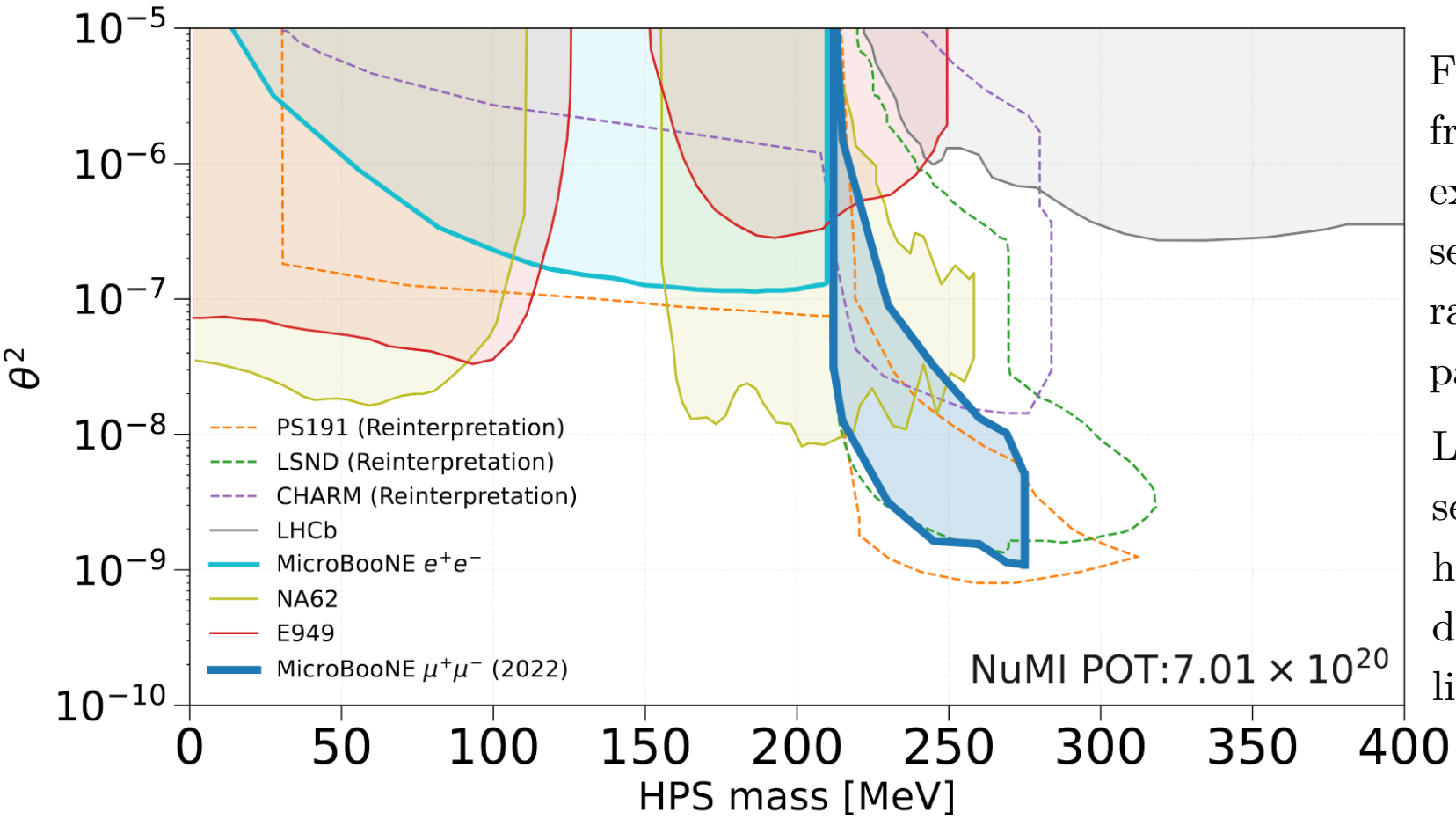
Latest MicroBooNE LLP results: HNLs



Order of magnitude improvement with respect to previous MicroBooNE result

Phys. Rev. D 106, 092006

Latest MicroBooNE LLP results: HPS



First constraints from a dedicated experimental search in this range of parameters

Lack of sensitivity at high coupling due to short lifetime

Phys. Rev. D 106, 092006

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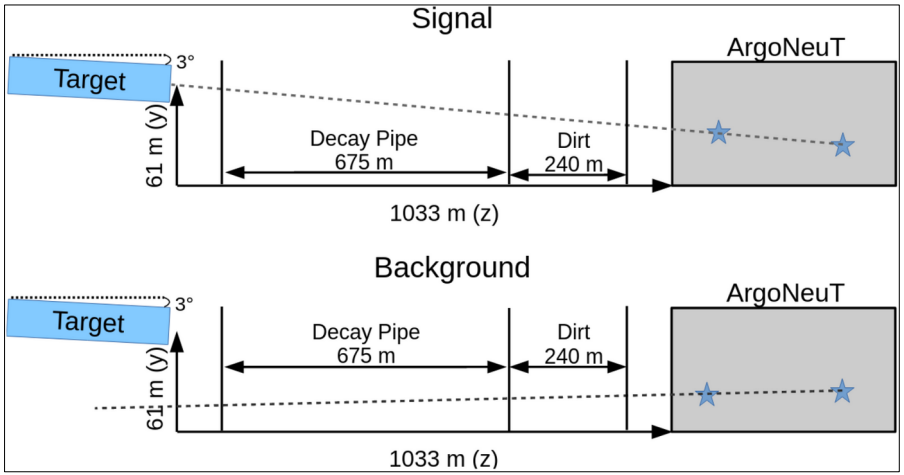
Other MicroBooNE BSM searches

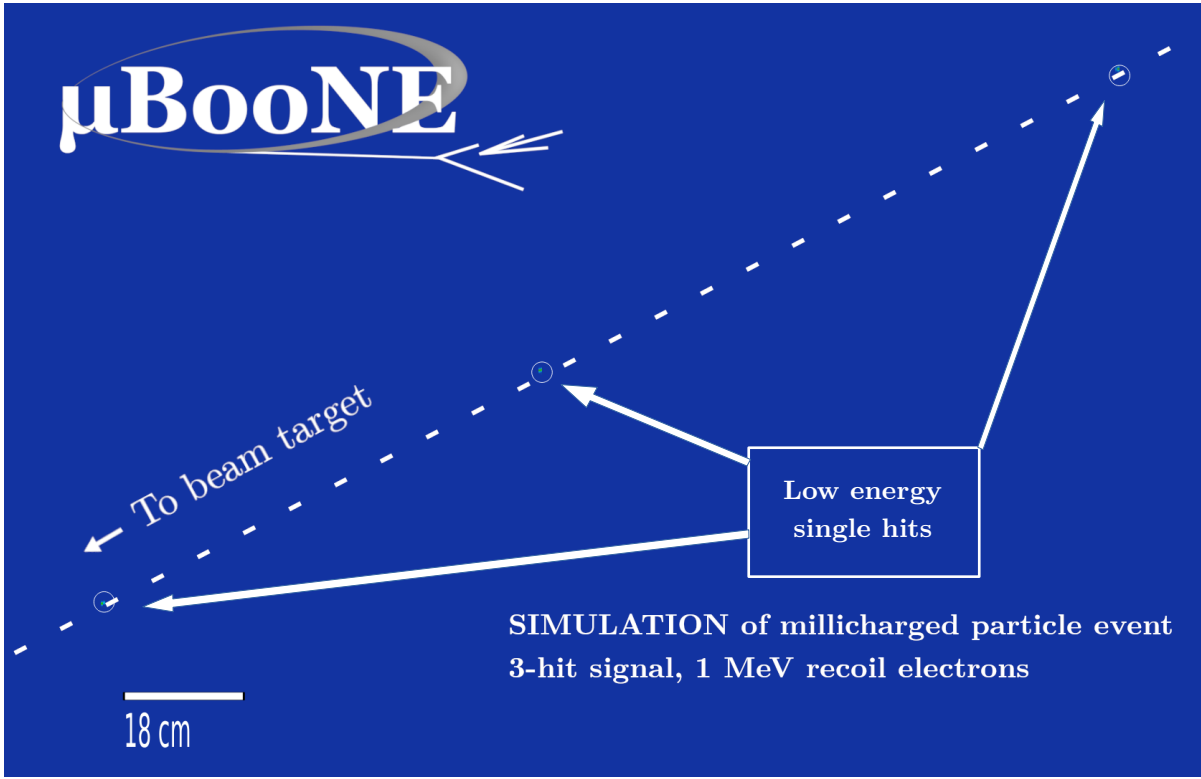
Other BSM: Millicharged particles (in progress)

Millicharged particles: feebly interacting LLPs with fractional charge

ArgoNeuT LArTPC performed such a search (on-axis with NuMI)



ArgoNeuT: [Phys. Rev. Lett. 124, 131801]

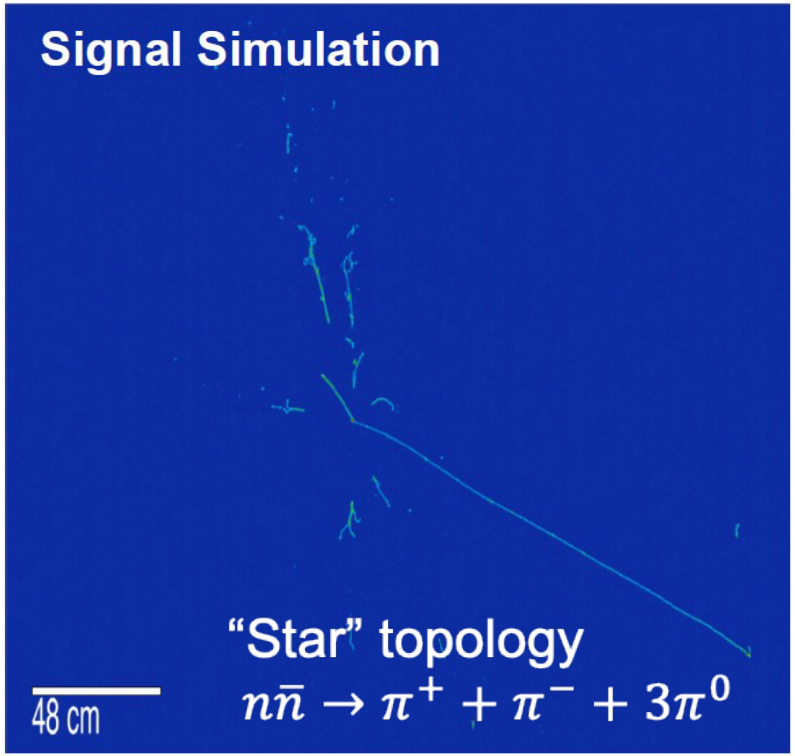


Isolated hits with argon electron in a straight line. Favors low-energy hits.

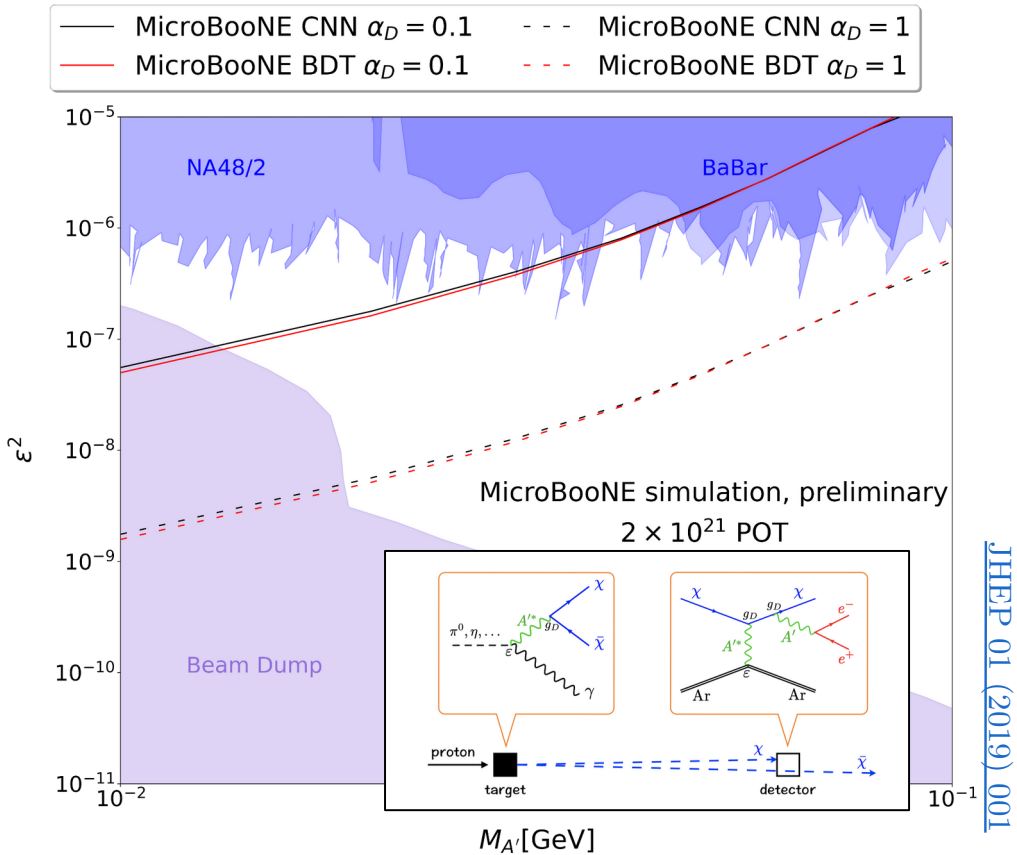
Other BSM (in progress)

Neutron-antineutron oscillations

MICROBOONE-NOTE-1113-PUB



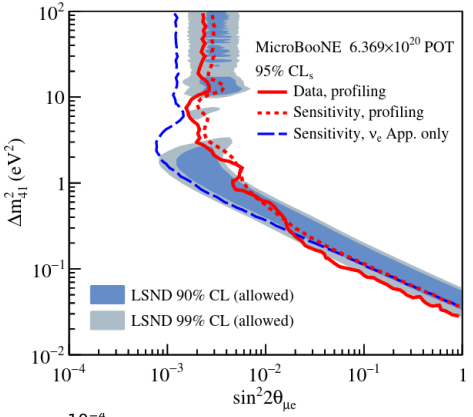
Dark tridents MICROBOONE-NOTE-1118-PUB

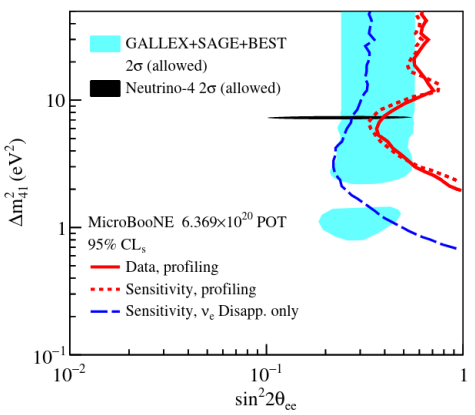


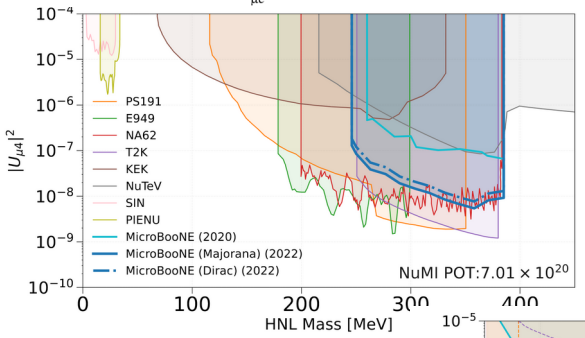
More HNL and HPS decay channels as well. Stay tuned!

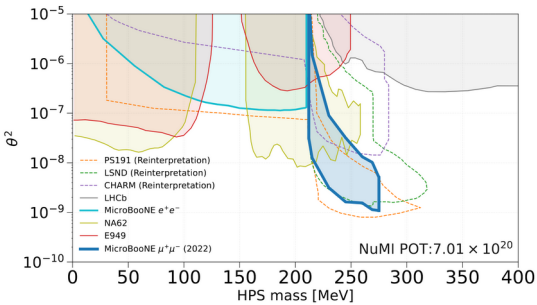
Summary

- Searched for 3+1 light sterile neutrinos leveraging our 2021 LEE results
  - Phys. Rev. Lett. 130, 011801
  - No evidence of sterile neutrino oscillations
  - Upcoming search combining BNB and NuMI will improve by breaking parameter degeneracy
- Shown latest results for a search of HNL and HPS
  - Phys. Rev. D 106, 092006
  - Expands upon previous results from 2020 and 2021
- LArTPCs capable of producing competitive results with complex signature topologies
- MicroBooNE has a rich BSM search program
  - Always something in the works!



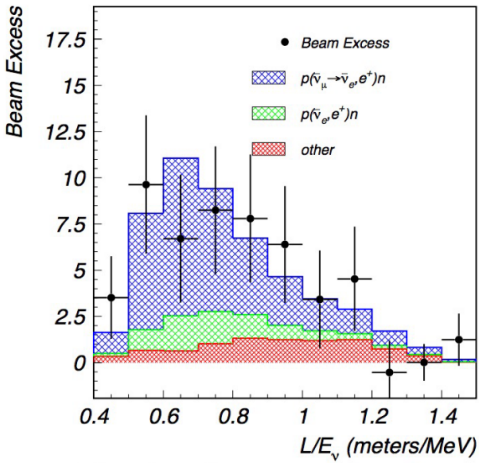




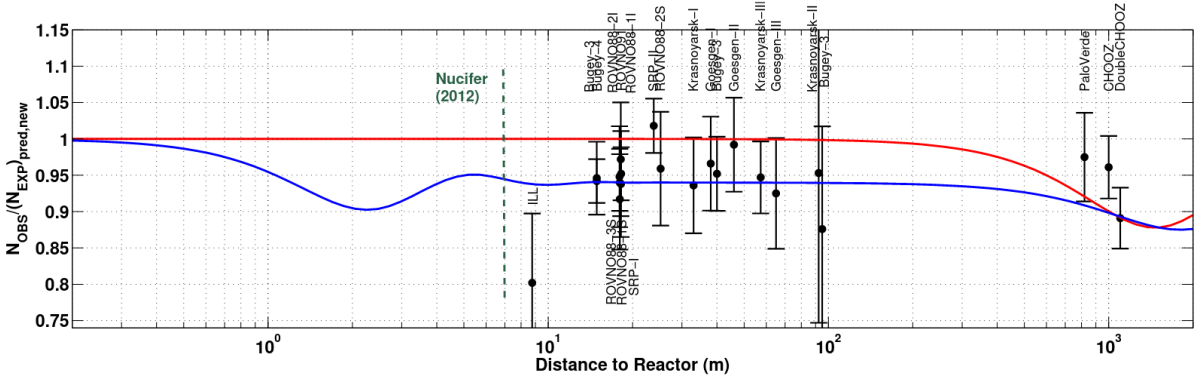


Backup

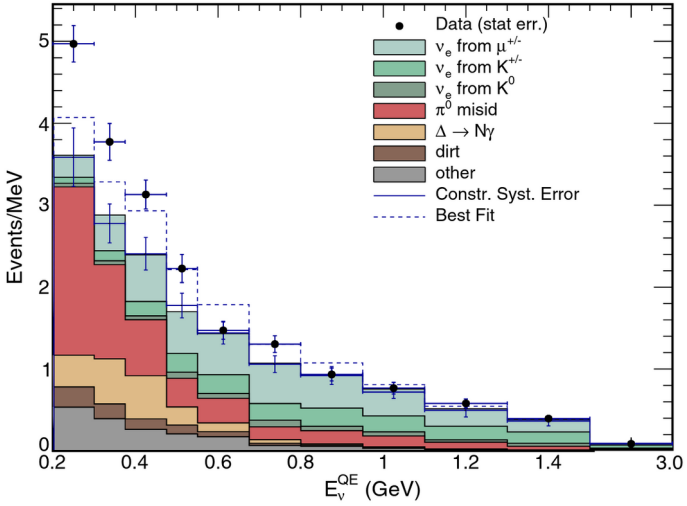
Short baseline anomalies



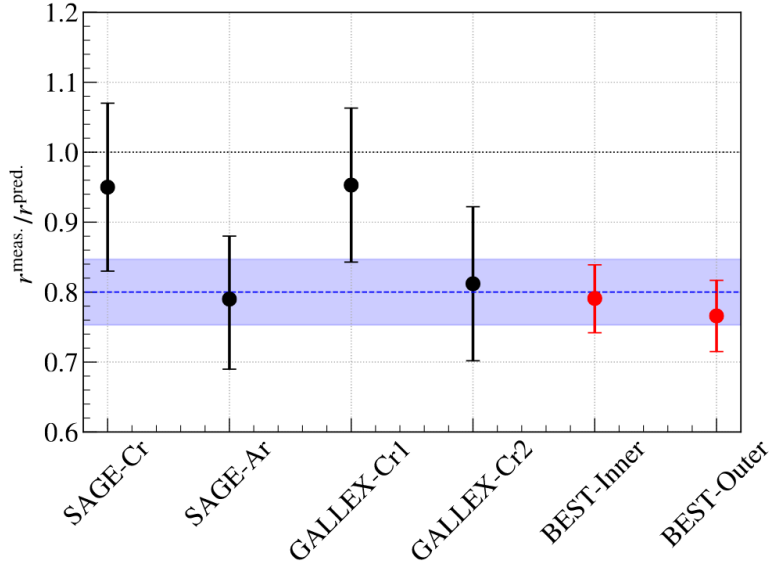
LSND excess
Phys. Rev. D 64, 112007



Reactor anomaly (anti ν_e deficit) (now likely resolved)



MiniBooNE low energy excess (LEE)
Phys. Rev. Lett. 121, 221801

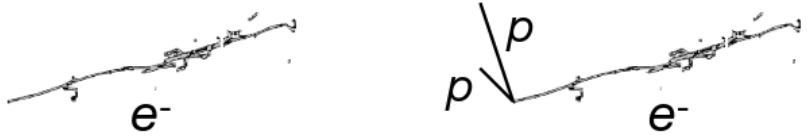


Gallium anomaly (solar ν_e deficit)
Phys. Rev. C 105, 065502

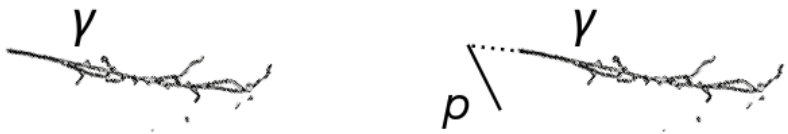
MicroBooNE search for the MiniBooNE low-energy excess

Searches using multiple topologies and reconstruction methods: Phys. Rev. Lett. 128, 241801
We found no evidence of a ν_e excess

Phys. Rev. D 105, 112003



Phys. Rev. D 105, 112004



Phys. Rev. Lett. 128, 111801

Phys. Rev. D 105, 112005

Overlapping e^+e^-

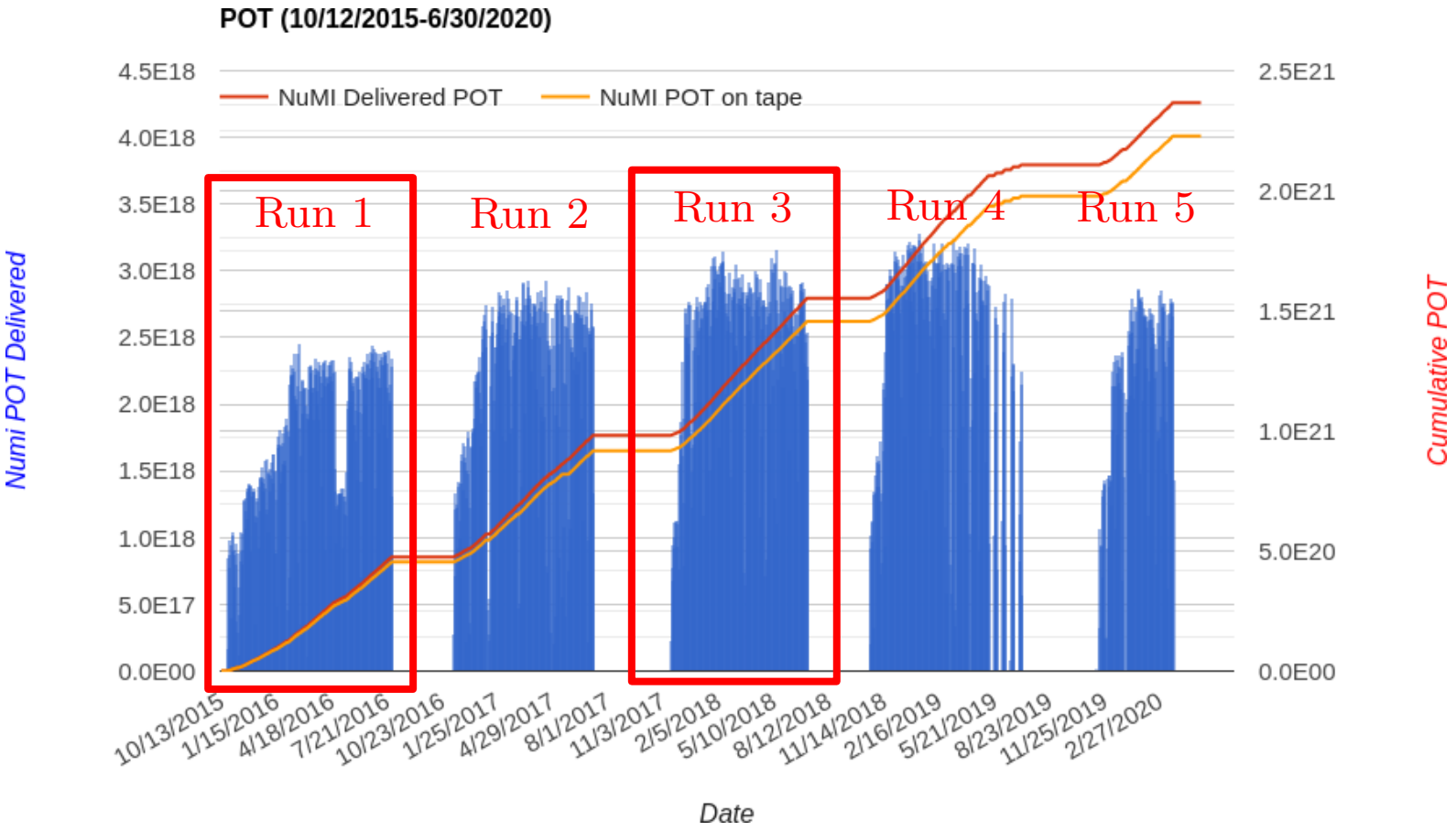
Overlapping e^+e^-

Highly asymmetric e^+e^-

Highly asymmetric e^+e^-

To be explored!

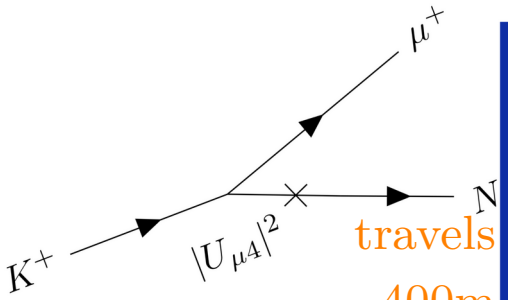
MicroBooNE data

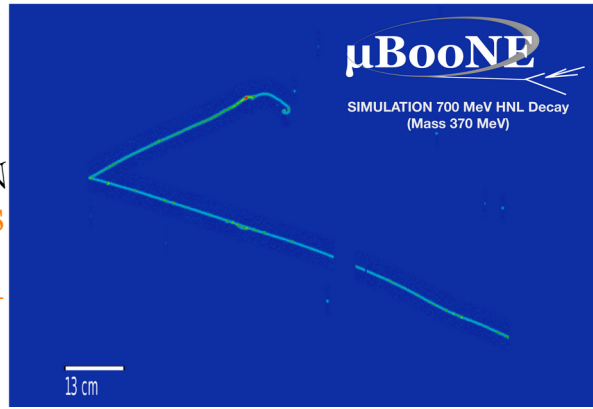


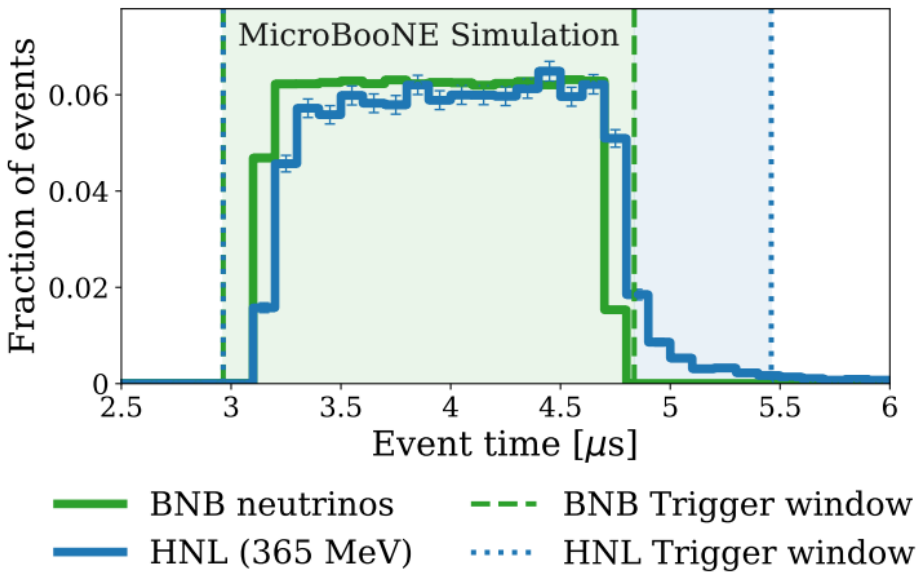
New HNL and HPS results use NuMI runs 1 and 3 data (~50% of dataset)

MicroBooNE first HNL search (2020)

- Phys. Rev D 101, 052001
- First search of HNLs in LArTPCs
- Produced at **BNB target**, using 2.0×10^{20} POT
- Novel "late trigger" window
  - HNLs take longer than neutrinos to travel → effectively removed neutrino background
- Set limits for 260-385 MeV







MicroBooNE previous HPS search (2021)

- Phys. Rev. Lett. 127, 151803
- Produced at **NuMI absorber**, decays to e^+e^-
- First BSM e^+e^- search of any LArTPC
- One candidate event, consistent with background expectation